SHORELINE EVOLUTION IN A GROIN FIELD
BY RESERVOIR MODEL APPROACH

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This paper introduces a simple approach for calculating shoreline change in a groin field based on a Reservoir Model previously derived for inlet morphology. Each compartment in a groin field is represented by one point that allows tracking of average volume in the compartment. Analytic solution of the governing equations explicitly shows the infilling of groin compartments from up- to down drift and gives the time delay in an explicit expression. The model is validated with a data set of shoreline position at Westhampton Beach, Long Island, NY.

INTRODUCTION

Groins are shore-perpendicular structures built to reduce recession of the local shoreline. In recent years, emphasis in groin design has been on their bypassing function, that is, the amount of material that a groin will allow to pass, and not on exclusive consideration of the amount of longshore transport captured by a groin or groin field. Modern coastal engineering functional design calls for placement of beach fill together with construction of groins to assure their bypassing capacity (Kraus et al. 1994). Existing groins or groin fields that cause extensive trapping may be adjusted by shortening the structures or placing a notch (lowering the groin elevation) on the landward end (Kraus 2000a; Wang and Kraus 2004).

Groin field design is greatly facilitated by 1-line mathematical models of shoreline change. Indeed, the seminal study in 1-line modeling considered shoreline change at a groin (Pelnard-Considère 1956). Such models have been greatly advanced to account for variable wave conditions, different lengths, permeability, and spacing of structures, and bypassing of sediment between adjacent groin compartments. Although as many as 27 fundamental parameters may govern the processes (Kraus et al. 1994), for typical sand beaches, four non-dimensional quantities are prominent in controlling groin field performance as: (1) bypassing, parameterized by the ratio of depth at groin tip to incident wave height; (2) ratio of net to gross longshore transport rates, (3) ratio of groin separation distance to groin length, and (4) structure permeability.

Although 1-line models are powerful and general, interdependence of the governing parameters is not readily apparent for groin fields. In this paper, a

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theory of shoreline evolution in groin fields is presented based on Reservoir Model concepts introduced for analyzing natural sand bypassing and morphology change at coastal inlets (Kraus 2000b). In a Reservoir Model approach, the time-dependent volume change for a specified region (e.g., groin compartment) is calculated based on the dependence between sand-sharing morphologic regions, as specified by the user. Application of the Reservoir Model allows reconnaissance examination of widely varying alternative groin field configurations and time-dependent longshore transport, with instantaneous solution on a standard PC. The approach is also applicable to coastal processes models of regional change, such as Cascade (Larson et al. 2002; Larson and Kraus 2003; Larson et al. 2006), in which accounting for volume change within the calculation period at a groin field is sufficient, without detailed knowledge needed of the change within a compartment. The Reservoir Model approach to beach response at groin fields is examined with shoreline position data newly analyzed for the Westhampton, Long Island, NY groin field.

THEORY

With reference to Fig. 1, for the i^{th} groin compartment, in a Reservoir Model the shoreline position is represented by its average value y_i from some baseline of maximum landward position (which may differ for each compartment). The compartment width is x_i, and lengths of the groins defining the compartment are L_i and L_{i+1}. With depth of active longshore transport D_i, the sand volume in the compartment is $V_i = D_i\, x_i\, y_i$. The dotted lines represent virtual groins specified as one way of implementing boundary conditions.

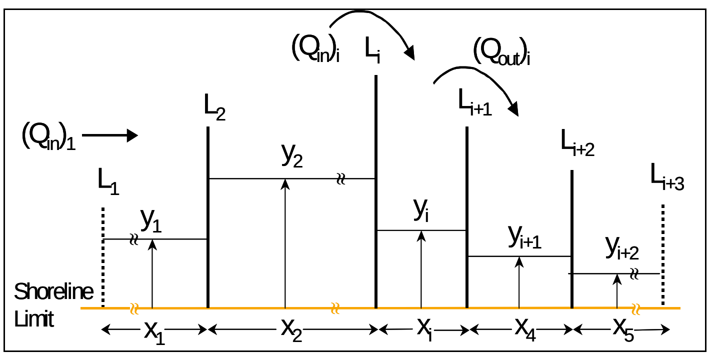

Figure 1. Plan-view sketch for general groin field in Reservoir Model.

Assuming that the beach profile shape remains constant, the continuity equation yields the change in shoreline position as,

$$\frac{dy_i}{dt} = \frac{1}{D_i x_i}\left[(Q_{in})_i - (Q_{out})_i\right] \tag{1}$$

where $(Q_{in})_i$ and $(Q_{out})_i$ are the input and output total longshore transport rates at the compartment, respectively. The Reservoir Model assumption is applied, that relates the output rate to the input rate, which in simplest form is linear,

$$(Q_{out})_i = \frac{y_i}{L_{i+1}}(Q_{in})_i \quad \text{or} \quad (Q_{out})_i = \frac{y_i}{L_i}(Q_{in})_{i+1} \tag{2}$$

depending on the direction of the input longshore transport rate as to the right or left, respectively. Eq. 1 can be solved numerically for arbitrary groin-compartment geometries and time-dependent longshore transport rate including changing direction, once Eq. 2 is specified.

The concept of the Reservoir Model as applied to groin compartments is summarized in Fig. 2. Each groin compartment can hold a certain maximum volume, which is considered its equilibrium volume. Bypassing is assumed to be linear, but this need not be, with a function specified to represent permeability.

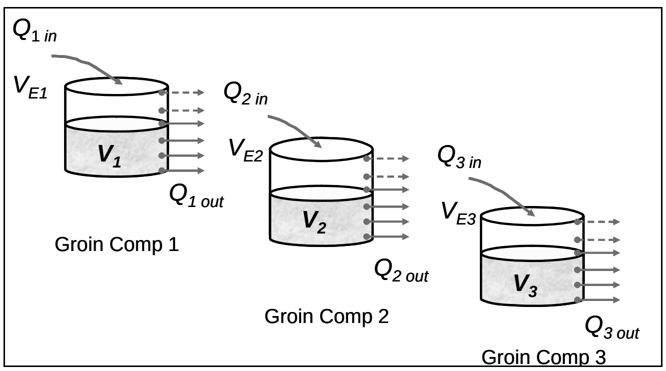

Figure 2. Concept of Reservoir Model applied to groin compartments.

To understand dependencies and functional form of the solution, a constant input rate Q_{in} from the left is specified at compartment 1, which is a virtual compartment on the up-drift beach. Combining Eqs. 1 and 2 gives:

$$\frac{dy_i}{dt} = \left(1 - \frac{y_i}{L_{i+1}}\right)\frac{1}{D_i x_i}(Q_{in})_i \tag{3}$$

The solution for the i^{th} groin compartment is,

$$y_i(t) = L_{i+1}\left[1 - \exp(-t_i / \tau_i)\right] \tag{4}$$

in which the quantity $t_i = t - \sum_{j=1}^{i-1} \frac{\tau_j}{L_{j+1}} y_j$, with $\tau_i = D_i x_i L_i / Q_{in}$, explicitly exhibits time-delay contributions from all up-drift compartments. For a constant input longshore transport rate, Eq. 4 indicates exponential growth toward filling, with increasing time delay for compartments further down drift in the groin field. The quantity τ_i is a characteristic time scale for filling (of the i^{th} compartment). The rate of bypassing from compartment i is its output rate, found to be $(Q_{out})_i = \prod_{j=1}^{i} \frac{y_j}{L_j} Q_{in}$, indicating all up-drift compartments contribute in determining bypassing.

In a general situation and typical application where the input rate changes in magnitude and direction with time, a numerical solution determines the sign of the transport and invokes the appropriate Reservoir Model equation of Eqs. (2).

SENSITIVITY TESTS

Selected model properties are demonstrated by numerical solution of Eq. (3) by trapezoidal integration, giving an unconditionally stable scheme for which large time steps (tenths of a year, for example) can be taken. Model output is obtained in a few seconds for large numbers of groin compartments in multi-year simulations. Two sensitivity tests are discussed with groin field configuration similar to that at Westhampton, NY, except for fewer groins.

Test 1. The test groin field has seven compartments with L_i = 150 m, $x_i = 3L_i$, D_i = 8 m, and Q_{in} = 50,000 m^3/year as right-directed transport. Shoreline change calculated after 50 years is shown in Fig. 3. A time delay in shoreline growth down drift is evident. Groin compartments 1-3 first fill substantially, depriving down-drift compartments and beach. Groin compartment 7 receives sand after 40 years.

Test 2. The conditions are the same as for Test 1, but with Groins 2, 3, and 4 shortened by half. Although the first three compartments fill, they require less volume, and more sand is bypassed down drift (Fig. 4). The time delay in filling compartments also decreases as compared to Test 1. Groin compartment 7 begins receiving sand after about 30 years.

WESTHAMPTON GROIN FIELD

The response of the shoreline to the groin field constructed at Westhampton Beach, located on the south shore of Long Island, NY, is well documented (Nersesian et al. 1992; Kraus et al. 1994; Bocamazo and Grosskopf 1999). Long Island is about 180 km long and trends 28 deg north of east (Figure 5). The gradient in longshore sediment transport rate increases from east to west, brought about by wave sheltering of the continental land mass to the north and to the south of the New York Bight. Rosati et al. (1999) review previous sediment budgets and develop a regional budget for the section Fire Island to

Montauk Point. Net values shown in Fig. 5 are compatible with Rosati et al. (1999) and Panuzio (1968). Transport tends to be to the west and strong during the winter, with reversals typical during the summer, but with weaker rates (fewer storms).

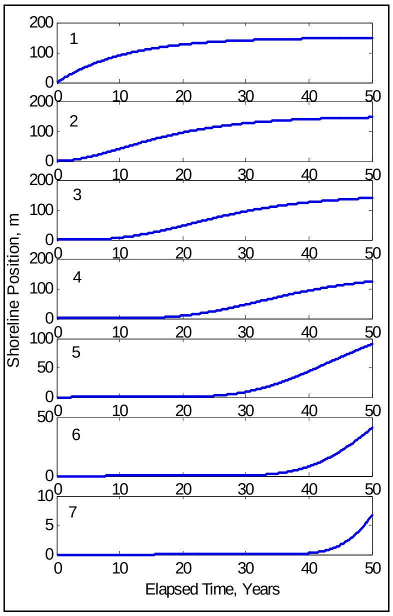

Figure 3. Equi-length groins (groin compartments 1-7, top - bottom).

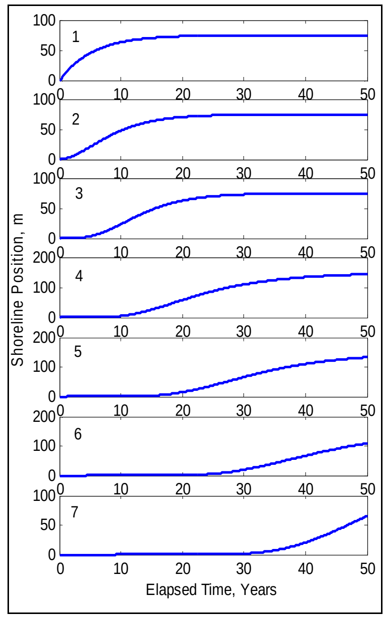

Figure 4. Groins 2-4 shortened (note scale change with Fig. 2).

In the past century, the barrier island was severely eroded by the hurricane of record in September 1938, and then again by extreme hurricanes and tropical storms in 1944, several storms in the 1950s, and an extreme northeaster in March 1962. The barrier island was overwashed and breached at many locations during these storms, often in the same locations. In 1960, storm-protection plans were authorized by the U.S. Federal Government for the coastal reach between Fire Island Inlet and Montauk Point. On of the reaches included was the barrier island that extends 24.6 km between Moriches Inlet to the west and Shinnecock Inlet to the east. As part of the plan, groins were constructed, initially on the most vulnerable section of the reach, called Westhampton Beach, with the objective of providing a wide beach and dune as a storm-protection measure. The quarry stone groins have an average spacing of 400 m and a length of 146.3 m, and were constructed with a tapered section roughly following the trend of the nearshore slope (Nersesian et al. 1992).

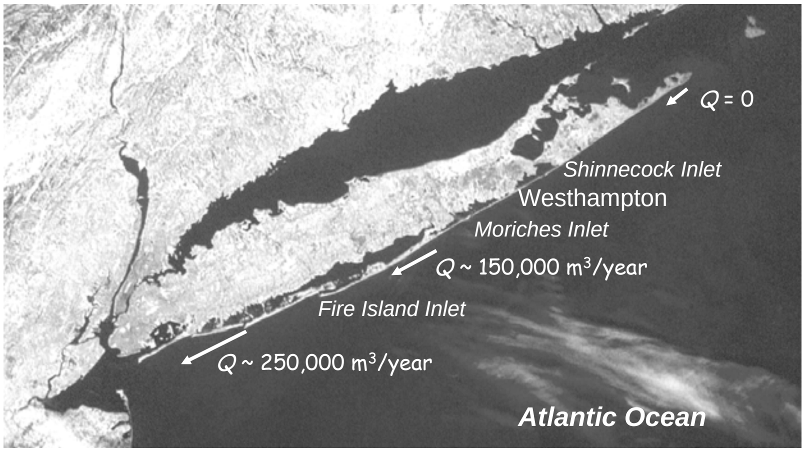

Figure 5. Location map for Westhampton, Long Island, NY.

Owing to political and economic considerations (Heikoff 1976), 11 groins were first constructed along 3.8 km of shore from summer 1965 to mid 1966, without placement of dunes and beach fill, which was to be provided by the local sponsor. The groins were mainly built westerly, possibly during a time of transport reversal, from a point 10.6 km east of Moriches Inlet. This initial work was supplemented in 1970 by Groins 12 -15, together with fill (Bocamazo and Grosskopf 1999), constructed along 1.8 km of shore to the west of the existing groins. The plan for continuation of groin construction to Moriches Inlet was not undertaken due to political decisions (Heikoff 1976). In December 1992, a major breach occurred along the shore directly to west of Groin 15. The breach was closed by hydraulic fill and, in 1996-1997, a tapered groin transition was created by shortening Groins 14 and 15 and building a short groin in-between them to allow bypassing from the groin field to the down-drift beaches to the west (Bocamazo and Grosskopf 1999).

For the present study, interest is mainly in shoreline response to the first 11 groins, because this field was not filled. Nersesian et al. (1992) document gradual down-drift infilling of the Westhampton groin field. Kraus et al. (1994) numerically simulated this documented infilling from east to west with the GENESIS model (Hanson and Kraus 1989), considered a milestone verification of the bypassing algorithm in the model. The next section introduces the reanalyzed shoreline position data set for Westhampton.

WESTHAMPTON SHORELINE POSITION DATA SET

Aerial photographs were acquired and analyzed for the dates 5/15/1962, 8/12/1965, 2/15/1966, 11/15/1968, 3/17/1970, 2/23/1972, 7/15/1975, 12/15/1979, 3/4/1980, 4/15/1983, 3/15/1988, and 3/31/1995. Some photosets covered the entire distance from Moriches Inlet to Shinnecock Inlet, although

occasionally a few frames were missing near one or the other inlet. A few of these photosets were recently found in the Beach Erosion Board archive (Morang 2003). The 1965 and 1980 photosets cover only the groin field. The photosets were scanned and then digitized through identification of the high-water line, a visually interpreted morphologic feature not directly related to a tidal datum, at 7.62-m (25 ft) intervals alongshore.

The photographic sequence in Figures 6-9 is adjusted to the same scale in showing an area of the barrier island breached during the 1962 storm (and at the same location by the 1938 hurricane and a 1958 storm). The dashed line is the approximate shoreline position after the 1962 storm, retained for reference in the sequence, as are the two solid lines showing the banks of the breach. Groin construction began in summer 1965, when there was likely a longshore transport reversal (meaning transport to the east or to the right in the photographs). By August 1965 (Fig. 7), the breach had filled, and a narrow beach had formed. By 1972 (Fig. 8), a beach berm had formed, allowing wind-blown sand to occur. Two decades later, in 2004 (Fig. 9), a wide and high, vegetated dune system and wide berm were established. The dunes were built by sand blown from the berm (ocean side) landward, as there is no sand source on the land side. Nersesian et al. (1992) analyzed beach profile data between 1962 and 1991 and found that the 14 groin compartments had trapped 1.8×10^6 m^3 above National Geodetic Vertical Datum 1929; most of this volume must have originated from sand blown off the beach berm.

Figure 6. Breach west of west bridge, Westhampton, at end of March 1962 storm.

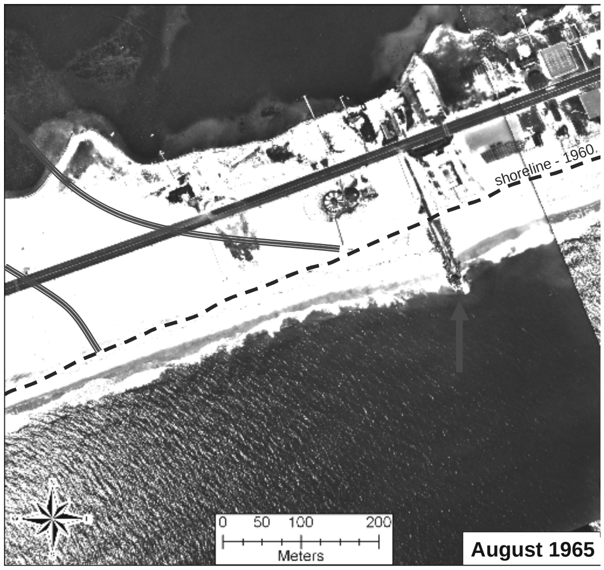

Figure 7. Breach area west of west bridge, and commencement of construction of Groin 6.

Figure 8. Breach area west of west bridge, Groins 7 and 6.

Figure 9. Breach area west of west bridge, 2004, showing wide, vegetated dune field and wide beach berm.

Shoreline change from Shinnecock Inlet to Moriches Inlet as obtained from four photosets is plotted in Fig. 10. Groin 1 (G1) and Groin 11 (G11) are labeled in the figure. In this regional view, a number of shore evolution features can be seen: growth of the down-drift attachment bar at Shinnecock Inlet, overall increase in beach width between the east end of the groin field and an area about 4 km west of Shinnecock Inlet; overall widening of the beaches after the 1962 northeaster; infilling of the compartments 1 to 10 from east to west; filled groin Compartments 11-13, and recession of the shoreline directly east of Groin 15.

Selected shoreline positions near the groin field are plotted in Figure 11. Besides a notable increase in beach width, infilling is observed from east to west of the compartments between Groins 1 and 11. Construction of Groins 11 through 15 and filling of their compartments alleviated the shoreline recession that occurred adjacent to and east of Groin 11 (Nov 1968). It is apparent that the compartments of the groins built in 1970 were filled.

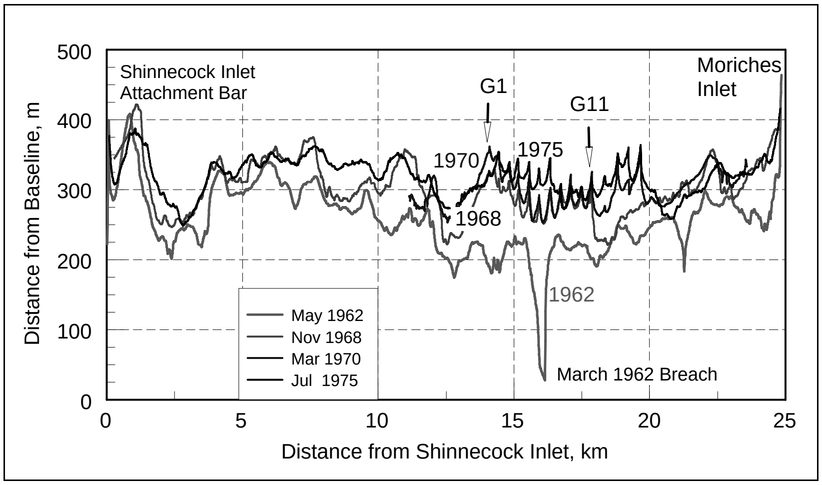

Figure 10. Shoreline position between Shinnecock Inlet and Moriches Inlet for four dates.

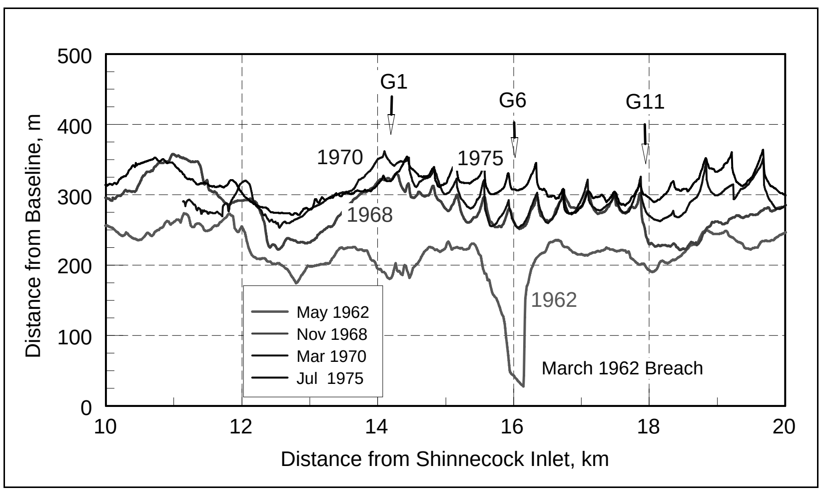

Figure 11. Shoreline position for four dates at the Westhampton groin field.

APPLICATION OF RESERVOIR MODEL TO WESTHAMPTON BEACH

Shoreline change that occurred between August 1965 and February 1972 was selected for modeling, as it represents a clear trend of change. Shoreline position as measured from the August 1965 photoset served as the initial shoreline for the modeling. Depth of active transport (top of berm to depth of

closure) was taken as 8 m. An annual net transport rate of 150,000 m^3/year to the right was specified, under the assumption that reversals would have been small in the groin field owing to the shoreline recession east and adjacent to Groin 11 for most of the 6.5-year simulation period. Figure 12 plots calculated growth of the shoreline for the first five groin compartments. From Compartment 6 and westward, the effective growth was negligible.

Reservoir Model predictions for the case study are summarized in Figure 13. The Reservoir Model represents shoreline position in a groin compartment with one point. Except for the over-prediction for Compartment 1, the model shows the trends in observed shoreline change. It may be that transport reversals could have removed sand from Compartment 1, which would not be accounted for in the present modeling. However, a more sophisticated version of the model could treat time series of the longshore transport rate.

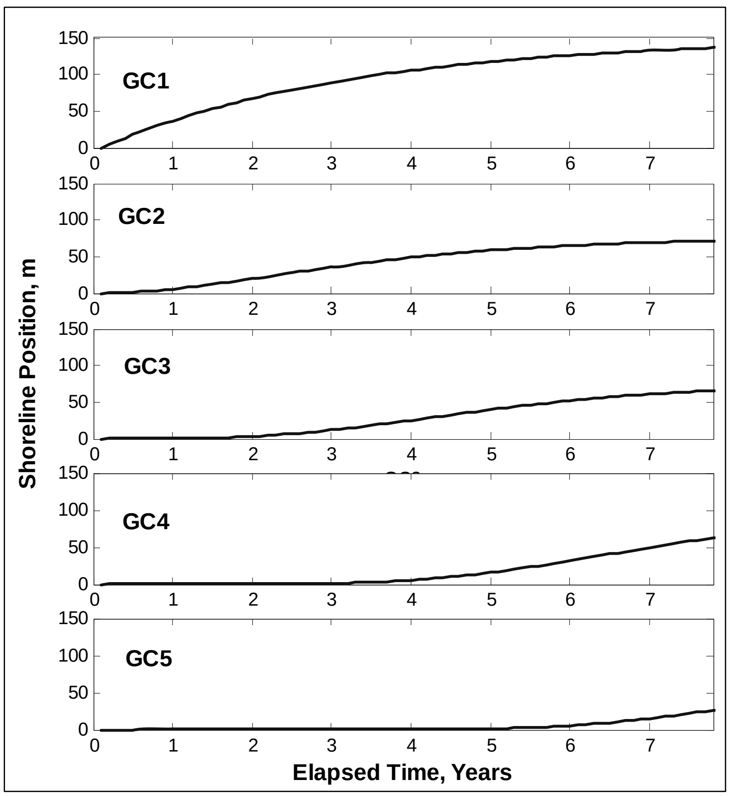

Figure 12. Rate of growth calculated in first five groin compartments.

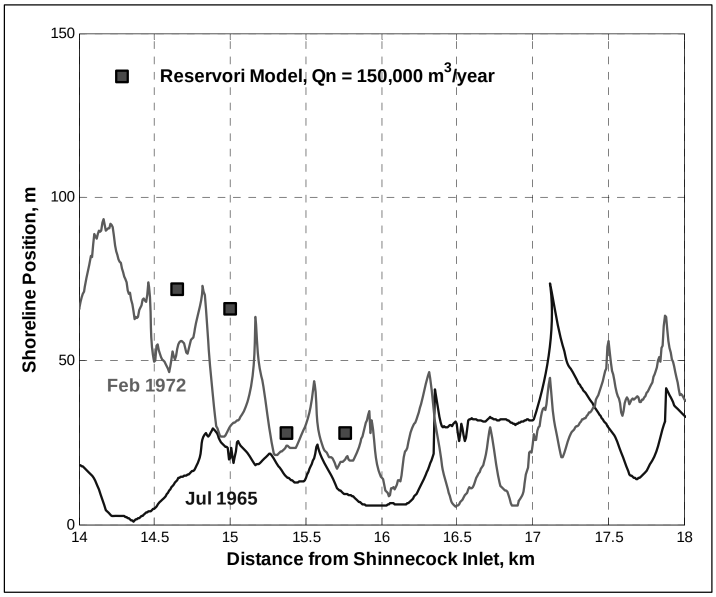

Figure 13. Comparison of measured and calculated shoreline change.

CONCLUDING DISCUSSION

The Reservoir Model approach for simulating shoreline change in a groin field was demonstrated to produce valid results for both direction of infilling and for magnitude of change at the Westhampton Beach groin field. Generalization of the model is possible to allow depth-dependent bypassing, and alternative definitions for the output rate are also possible, besides a linear rate (Kraus 2000b). The case study for Westhampton demonstrated that wind-blown sand from the ocean side can be a substantial contributor to dune build-up. The Reservoir Model does not replace more detailed shoreline change models, but it augments them in providing an efficient means of representing groin fields in regional modeling of coastal processes, such as in the Cascade model (Larson et al. 2002; Larson and Kraus 2003; Larson et al. 2006).

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